Journal of Agrometeorology

ISSN : 0972-1665 (print), 2583-2980 (online)
Vol. No. 25 (2) : 287 - 292 (June- 2023)
DOI : https://doi.org/10.54386/jam.v25i2.1954
https://journal.agrimetassociation.org/index.php/jam

Research Paper

Spatial estimation of water requirement in greengram under projected climates for North Interior Karnataka

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ABSTRACT

Greengram is one of the major protein rich grain legumes predominately cultivated in North Interior Karnataka (NIK). Due to erratic nature of monsoon which has increased with climate change greengram crop is suffering from moisture stress and hence the large variability in yield levels is noticed. The study aimed at determining the water requirement of greengram variety DGGV- 2 using CROPWAT model that helps the farmers of NIK consisting of 12 districts in tapping the potential yields of this crop through proper irrigation management. The results revealed that average crop evapotranspiration (ET_c), effective rainfall (ER) and irrigation requirement (IR) under past climates (1991-2020) for NIK were 246, 269.3 and 37.4 mm, respectively. An increase of 26.8 mm in ET_c, 21.6 mm in ER and decrease of 0.3 mm in IR were simulated under projected climates. Among the four dates of sowing (7, 14, 21 and 28th June) for greengram delayed sowing *i.e.,* on 28th June under projected climate (2021-2050) simulated the lowest water requirement and irrigation requirement for all the 12 districts of NIK. This study proved that the CROPWAT model is useful to foresee crop water demand under projected climates and calculate the crop irrigation needs in supplement to projected rainfall for proper management of water resources and maintain crop yields.

***Keywords*:** CROPWAT, Crop evapotranspiration, Effective rainfall, Irrigation requirement and NIK

Greengram (*Vigna radiata* L.), an important short-duration leguminous crop of tropical regions of the world, is native to India and Central Asia. In India, where majority of population is still vegetarian, and pulses are the main and cheap source to meet the required dietary protein, pulses occupy 65% of the global area and contribute 54% of the total production (Praveena *et al*., 2018). Greengram occupies an area of 3.4 m ha with a production of 1.42 m t contributing 11% to the total annual pulse production in India (Movalia *et al*., 2020). In Karnataka it is grown in area of 453 thousand hectares with production and productivity 181.94 thousand tonnes and 402 kg ha^{-1}, respectively (Anonymous, 2021).

Greengram is typically grown on uncongenial soil and climatic environments (Mondal *et al*., 2018) as a rainfed crop in dryland farming systems where, it more often than not, experiences soil moisture stress at one or the other stage of the crop duration (Yadav *et al*., 2019). Hence, the average productivity of greengram under rainfed situation is very low (468 kg ha^{-1}) as its cultivation is mainly confined to marginal and sub-marginal lands of poor soil fertility status with sub-optimal agronomic practices without any assured irrigation (Saravanan *et al*., 2013). North Interior Karnataka (NIK) is one of the drier regions of India receiving on an average 550-650 mm rainfall per annum (Anonymous, 2016). Greengram is cultivated in all the 12 districts of NIK with the early showers of South-West monsoon *i.e.,* in the first week to third week of June. It becomes an important pulse in this region as it can yield better with minimal water requirement and can escape dry spells because of the short crop period (65-75 days). The increase in MSP and government procurement from last few years has encouraged the farmers of NIK to further choose greengram in their cropping system.

Water is one of the most important environmental

***Article info - DOI*:** https://doi.org/10.54386/jam.v25i2.1954
Received: 18 November 2022; Accepted: 05 April 2023; Published online : 25 May 2023

factors determining the growth and sustainable productivity of crops. Greengram, despite being a short duration crop, like many crops, is very sensitive to moisture stress during flowering and pod development stage (Mondal *et al*., 2018). Stress at these stages eventually reduces photosynthesis rate, metabolic processes, nutrient uptake, total biomass and economic yield (Jeshni *et al*., 2017). The crop water requirement and irrigation requirement of any given crop depends on its management, water availability, soil and climatic conditions of a given location. There is a need to quantify crop water requirement and to identify suitable time, and amount of irrigation in order to attain maximum yield in the face of projected climate change and expected moisture stress due to erratic and variable rainfall. Shaloo *et al.,* (2023) reported spatio-temporal variation in crop water requirement of maize crop in Haryana state while Masina *et al*., (2022) estimated irrigation water requirement in groundnut and sunflower crops in Odisha using CROPWAT model. Hence, the present investigation was undertaken to quantify the crop water and irrigation requirement of greengram for the past climates and for the projected climate change using crop water simulation model CROPWAT for the benefit of greengram growing farming community from NIK region.

MATERIALS AND METHODS

The NIK region considered for the present study is one of the meteorological sub-division as per IMD, New Delhi classification. It is located in semi-arid plateau at an altitude of 300-730 meters and constitutes the northern part of the Karnataka state. It has 12 districts namely Bagalkote, Belagavi, Ballary (including Vijayanagar), Bidar, Dharwad, Gadag, Haveri, Kalaburgi, Koppal, Raichur, Vijayapura and Yadagiri (Fig. 1). Greengram crop variety DGGV-2 was considered for the simulation study which is one of the high yielding and tall growing cultivar aiding mechanical harvesting with a duration of 75 days and released by the University of Agricultural Sciences (UAS), Dharwad.

CROPWAT model was used to quantify the crop water and irrigation requirement of greengram for the past climate (1991-2020) and projected period (2021-2050) for the entire NIK region. CROPWAT is a computer program-based model developed by Land and Water Development Division of FAO, and is an irrigation management and planning model simulating the complex relationships of on-farm parameters *viz*., climate, crop, management and soil. It simulates and estimates the reference evapotranspiration, crop evapotranspiration, irrigation schedule and agricultural water requirements for chosen crops with different cropping systems chosen by the user for irrigation planning (Muhammad, 2009).

The past weather data (rainfall, minimum and maximum temperature) for each of 12 districts of NIK was collected from NASA POWER web portal for the period of past 30 years (1991-2020) (https://power.larc.nasa.gov) and the projected data for the period of next 30 years (2021-2050) was collected from Copernicus Climate Change Service (IPSL-CM5A model) (https://climate.copernicus.eu) for RCP 6.0 scenario. This was done as all the weather parameters required for CROPWAT model from each of 12 districts of NIK for the past and future period was not available. The salient monthly characteristics of past and projected climate for the study area are presented in Table 1.

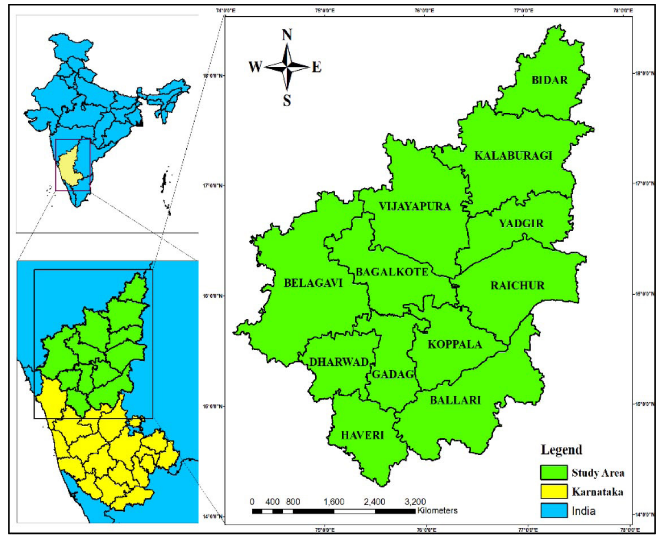

Fig. 1: Spatial map of 12 districts of North Interior Karnataka

The field experiment was conducted at Main Agricultural Research Station (MARS), UAS, Dharwad during *Kharif* seasons of 2020 and 2021. The phenological data for initial, mid and late growth stages of greengram variety DGGV-2 were collected from the field experiment and were used in the model as cultivar specific input data. The salient details of greengram crop required by the model *i.e.,* crop coefficients (Kc), phenological days, critical soil moisture depletion fraction (p) and yield response factor (Ky) were taken from some 18 published data of FAO (Allen *et al*., 1998). The soil data on total available soil moisture content (SMC), initial soil moisture depletion, maximum rooting depth and maximum rain infiltration rate for black clay and red sandy loam soils for each of 12 districts of NIK were collected from the recorded / estimated data from the World Bank funded Sujala project, UAS, Dharwad. The crop growth is simulated across four dates of sowing from 7th June to 28th June at weekly interval so that this sowing window (whole month of June) represents optimal sowing period across NIK region. The spatial interpretation of the model outputs across 12 districts of NIK was done using ArcGIS software.

RESULTS AND DISCUSSION

Reference evapotranspiration (ET_o)

All the districts of NIK showed an increase in the ET_o under projected climates compared to past during greengram cropping period (i.e., June to September) except for Koppal, which showed no change in the ET_o (Fig. 2). Though ET_o increased in the months of June and July in Koppal district under projected climates, the increased ET_o was masked by decrease in ET_o during August and September. Among all the districts of NIK, the highest increase in ET_o was simulated for Ballari district (24 mm month^{-1}) (Fig. 2) because of the highest increase in average temperature during June to September months (Table 1). Under projected climate, ET_o increased in June and July months of greengram cropping period (June-September) by 41 and 26 mm, respectively, while there was negligible change in August and September months (Fig. 3). This was mainly due to late onset or decreased rainfall in the month of June and increased rainfall in August and September months. Ali

Table 1: Average weather data during greengram cropping period (Jun-Sept) of all the 12 districts of NIK for the past climate (1991 - 2020), the projected climate (2021 – 2050) and the difference between the two periods

Districts	Past climate (1991-2020)			Projected climate (2021-2050)			Difference between Past & Projected climate		
	Rain (mm)	Temp (˚C)	RD	Rain (mm)	Temp (˚C)	RD	Rain (mm)	Temp (˚C)	RD
Bidar	640	26.7	108	812	30.2	81	172	3.6	-27
Bagalkote	444	26.1	95	804	28.4	84	360	2.4	-10
Belagavi	959	25.2	119	637	28.3	85	-322	3.1	-34
Vijayapur	397	27.0	81	819	28.3	87	422	1.4	5
Ballari	419	26.3	82	784	30.1	85	364	3.7	3
Dharwad	870	25.0	117	637	28.3	85	-233	3.3	-34
Gadag	521	25.7	106	652	28.2	88	131	2.5	-19
Kalaburagi	531	27.2	98	809	30.3	79	278	3.1	-19
Haveri	986	25.1	119	652	28.2	89	-333	3.1	-30
Koppal	393	26.2	26	582	28.2	89	189	2.0	63
Raichur	453	27.5	85	802	30.3	84	349	2.8	-3
Yadagiri	461	27.4	93	802	30.3	84	341	2.9	-9
NIK	**589**	**26.3**	**94**	**733**	**29.1**	**85**	**143**	**2.8**	**-9**

*Temp- Temperature, RD- Rainy days

et al., (2009) from Bangladesh concluded that the ET_o estimates are most sensitive to maximum temperature and least sensitive to minimum temperature. The order of sensitivity noticed was; maximum temperature > relative humidity > sunshine duration > wind speed > minimum temperature.

Crop evapotranspiration (ET_c)

In tropics, agricultural crops are extensively cultivated under rainfed conditions, where availability of water is not assured. So, in order to improve water use efficiency, it is essential to understand how much water is required by the crops in different periods (Hatfield and Dold, 2019). For greengram, the highest ET_c (275.4 mm) for the past climate (1991-2020) averaged across four DOS was simulated for Vijayapur district followed by Kalaburagi (274.2 mm) (Fig. 4). This was because of the highest average temperature recorded (27 ˚ C) and average ET_o (4.6 mm day^{-1}) simulated during the greengram cropping season in Vijayapur district. The lowest average ET_c (208 mm) was simulated for Belagavi district followed by Haveri (210.6 mm) due to the lowest values of average temperature (25.2˚**C**) and average ET_o (3.7 mm day^{-1}) recorded during greengram cropping period in Belagavi district (Table 1 & Fig. 2). The ET_c calculated for greengram crop using water balance equation by Srinivas and Tiwari (2018) was 210.54 mm and was the highest at development stage of the crop (20-30 DAS), which agree with the simulated values of the present study.

For the projected climate (2021-2050), the highest ET_c was simulated for Bidar district (293.2 mm) followed by Kalaburagi (292.6 mm) and the lowest was for Haveri district (251.1 mm) followed by Koppal (251.9 mm). The highest average temperature (30.2 ˚ C) and average ET_o (151 mm month^{-1}) during the cropping period was simulated for Bidar district. In contrast, the lowest average temperature and average ET_o during the cropping period (28.2 ˚ C and 131 mm month^{-1}) was simulated for Haveri district (Table 1 & Fig. 2). Interestingly, Vijayapur district showed negligible (0.2 mm) variation in the ET_c during the projected climates compared to the past despite increased temperature as it was masked by decreased ET_o due to increased rainfall during the same period in projected climates compared to past period (Table 1). All the districts showed increased ET_c during projected climates compared to the past due to increased average temperature and ET_o during the cropping period except for Koppal district where ET_c reduced by 7.1% compared to the past (1991-2020). Boonwichai *et al.,* (2018) estimated ET_c for rice which increased during projected climates (2020-2044) under both RCP 4.5 and RCP 8.5 scenarios. As excepted it was higher for RCP 8.5 scenario than RCP 4.5 because of higher temperature in the former scenario, and simulated values of this study confirms the past findings.

The ET_c was simulated to be declining with delay in sowing in all the 12 districts of NIK both in past and projected climates (Table 2). This was due to decreased average temperature and ET_o, and increased rainfall with delayed sowing.

Effective rainfall (ER) during greengram cropping period

The effective rainfall is that fraction of the rainfall which is stored in the soil and is available for the crop to meet its consumptive use (Avinash *et al.*, 1990). In general, the efficiency of rainfall decreases with increasing rainfall. Effective rainfall is related to the moisture available in the plant's root zone, allowing the plant to germinate, emerge and maintain its growth and development. Soil moisture levels need to remain above the wilting point for better growth of plants. Only a portion of heavy and high intensity rains during crop period can enter and be stored in the root zone and therefore, effectiveness of this type of rainfall is low whereas, frequent light rains during crop period are close to 100 per cent effective (Kumar, 2018). The highest ER recorded during the greengram cropping season was in Belagavi district (371 mm) followed by Dharwad (360 mm) and the lowest was in Koppal district (197 mm) followed by Vijayapur (201 mm) for the past climates (Fig. 5). Belagavi recorded a rainfall of 959 mm (Table 1) during June to September (*i.e.,*81% of annual rainfall of Belagavi) in past climates. Most days of these months were rainy days indicating even distribution of rainfall throughout and the highest among all the 12 districts in the past climate. Koppal district recorded 393 mm

Table 2: Average crop evapotranspiration (ET_c), effective rainfall (ER) and irrigation requirement (IR) in greengram for the four dates of sowing (DOS) across past (1991-2020) and projected (2021-2050) climates of NIK.

Particulars	Past Climate				Projected Climate			
	07-Jun	14-Jun	21-Jun	28-Jun	07-Jun	14-Jun	21-Jun	28-Jun
ET_c	250.2	246.3	244.3	243.1	292.2	278.2	265.6	255
ER	270.2	270.4	268.6	268	248	277.4	307.4	330.6
IR	37.2	36.5	35.4	40.3	80.1	44.6	13.8	9.8

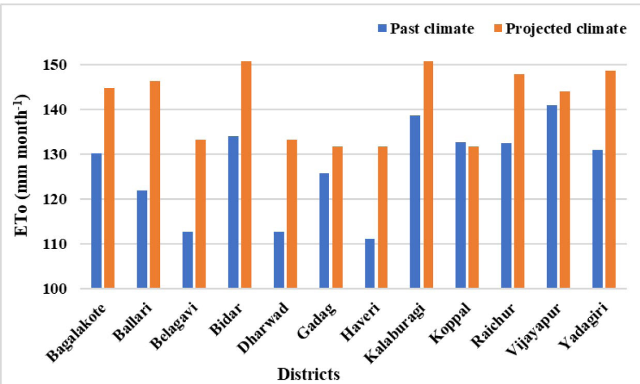

Fig. 2: Average reference evapotranspiration (ET_o) for greengram cropping period (June-September) during past (1991-2020) and projected (2021-2050) climates of all districts of NIK

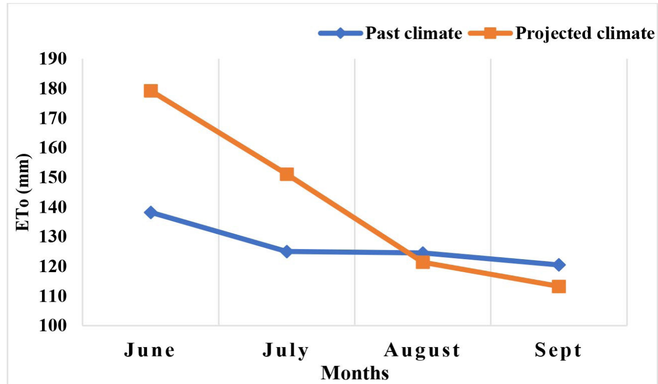

Fig. 3: Monthly variation of reference evapotranspiration (ET_o) during greengram cropping period for NIK

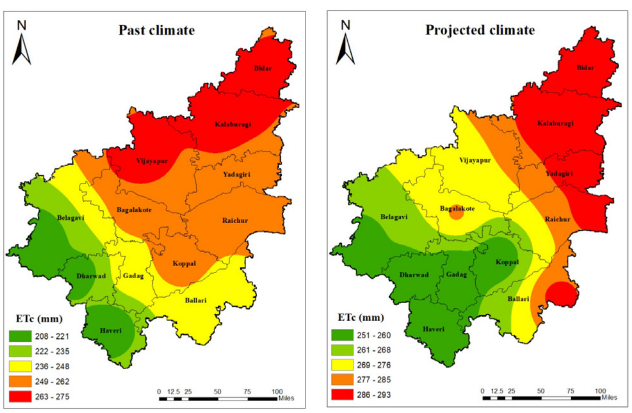

Fig. 4: Spatial distribution of crop evapotranspiration (ET_c) of greengram under past (1991-2020) and projected (2021-2050) climates across NIK.

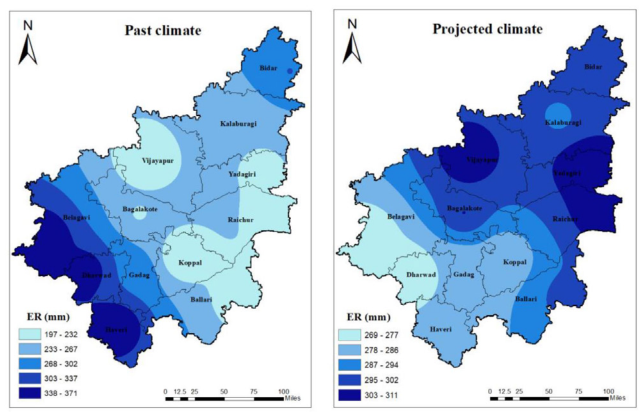

Fig. 5: Spatial distribution of effective rainfall (ER) in mm during greengram crop period under past (1991-2020) and projected (2021-2050) climates across NIK.

of rainfall during June to September (62 % of annual rainfall) with 26 rainy days i.e., the lowest rainfall and least number of rainy days among all the 12 districts of NIK in the past climates.

For the projected climates, the highest ER was simulated for Vijayapur district (311 mm) and the lowest for Belagavi and Dharwad districts with 269 mm ER (Fig 5). Vijayapur district simulated a rainfall of 819 mm during June to September (*i.e.,*77% of annual rainfall) with 87 rainy days, the highest among all the 12 districts in the projected climates. Belagavi and Dharwad districts simulated 637 mm (67% of annual rainfall) rainfall during June to September (Table 1), but the lowest rainfall after Koppal among the 12 districts of NIK in the projected climates. Bidar, Belagavi, Dharwad, Gadag and Haveri districts showed decreased ER in the projected climates compared to past while, remaining seven districts showed increased ER.

The ER decreased with delay in sowing in past climates for Bagalkot, Belagavi and Dharwad districts. Since, these districts get sufficient rainfall in the early days of the sowing which naturally saturates the soils, increasing seepage loss of rainfall in the later months of crop period. The effective rainfall has increased with delay in sowing in the remaining eight districts of NIK. This was due to minimal rainfall with early sowing and increased rainfall in the later stages. In the projected climates all the districts recorded increased ER with delay in sowing (Fig. 5) due to decreased rainfall in the month of June and increased rainfall in the month of July and August compared to the past climates.

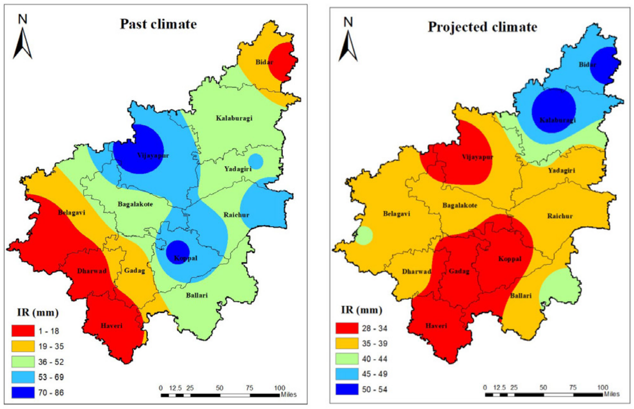

Fig. 6: Spatial distribution of irrigation requirement (IR) in mm for greengram croping period under past (1991-2020) and projected (2021-2050) climates across NIK

Irrigation requirement (IR)

Among all the 12 districts of NIK, the highest IR for greengram cropping period was simulated for Vijayapur district (85.6 mm) followed by Koppal (76.1 mm) for the past climates because of higher ET_c and the lowest ER during the cropping period. The lowest IR was simulated for Belagavi and Dharwad districts (1.2 mm) (Fig. 6). This can be explained by higher ER and lower ET_c during greengram cropping period. In case of projected climates, the highest IR was simulated for Kalaburagi district (54 mm) followed by Bidar (50.1 mm) and the lowest for Haveri district (28.4 mm) followed by Koppal (28.7 mm). For Kalaburagi and Bidar district the highest ET_c were simulated under projected climates with lower ER and increased average temperatures affecting the IR. Similarly, Bidar, Belagavi, Dharwad, Kalaburagi, Gadag and Haveri districts are expected to have increased IR in the projected climates compared to past during the crop period because of decreased ER whereas, remaining six districts showed decreased IR. The DSSAT model simulated results for rice crop in Thailand (Boonwichai *et al.*, 2018) showed that IR increased in the projected climates (2020-2044) under RCP 4.5 and RCP 8.5 scenarios. However, it was quite high for RCP 4.5 than RCP 8.5 because of higher ER under RCP 8.5.

With delay in sowing during the past climates, the Belagavi, Dharwad and Haveri districts simulated no IR in the first three DOS (7, 14 and 21st June) and negligible IR of 5 mm for the fourth DOS (28th June) sown crop and the reason being surplus rainfall during the cropping period at early stage of the crop in these districts. Bagalkot, Ballari, Gadag and Koppal districts showed increased IR with delay in sowing due to increased ET_c with late sown crop. Vijayapur district showed constant IR of 85-86 mm across DOS because of the constant rainfall of 90-98 mm for each month of the cropping period (June to September) and remaining four districts showed decreased IR because of increased ER with delay in sowing. In the projected climates all the districts showed decreased IR with delay in sowing (Table 2). This can be explained by the increased ER and decreased ET_c with delay in sowing in all the districts. These findings not only help to foresee crop growing conditions in future climates, but also help on how to manage to realize higher yields.

CONCLUSION

The rainfall under projected climate during the greengram cropping period (June to September) increased by 143 mm compared to past for NIK region. There is a shift in rainfall pattern under projected climates from normal onset (June) to delayed onset of monsoon. This shift caused increase in average temperature by 2.8 ^{0}C and ET_c coupled with reduced frequency of rainy days i.e., decreased effective rainfall at higher intensity under projected climates over past climates. Thus, irrigation water requirement of greengram sown on first fortnight of June is simulated to increase than delayed sowing under projected climates. Thus, in the context of saving water for the future and increased productivity it is suggested to delay the greengram sowing by nearly a month. Further, the present study highlights the role of breeders in developing the varieties that are suited for delayed sowing to increase the productivity of greengram and attain yield sustainability for the farmers of NIK under changing climate in the coming years.

ACKNOWLEDGEMENT

Authors thank the University of Agricultural Sciences, Dharwad, India for providing the facilities to conduct the research work.

***Funding*:** No funding is involved. The facilities provided by the University has been duly acknowledged.

***Conflict of interest*:** The authors declare no known conflict of interests that could have appeared to influence the work reported in the present paper.

***Data availability*:** The data presented in the present research paper is self-explanatory and for any further data accessibility do contact the corresponding author.

Author's contribution: **H. Thimmareddy:** Conceptualization, Investigation, Data curation and writing first draft, **R. H. Patil:** Guidance, formal analysis and interpretation, **K. G. Sumesh:** Guidance and overview, **G. Math:** Guidance and overview, **M. B Nagangoudar:** Review and editing and plagiarism

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